Analytic and numeric model for field-emission scanning probe lithography

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Sub-10 nm patterning is achievable with field-emission scanning probe lithography (FE-SPL) which uses field emission of electrons from nanotips (apex radii below 20 nm) for the direct exposure of an ultrathin resist film (thickness below 50 nm). Unfortunately, the forecast of the achievable line width for a given tip geometry and parameter set is not yet available. Nevertheless, a reliable prediction is essential to yield optimal results for a given nanotip and to get to the physical resolution limits of the FE-SPL technique by optimizing tip properties and parameters.
In this paper we present a numeric and an analytic model of the FE-SPL process. The numeric simulation model includes an electric field calculation between tip and sample, the field emission process of the electrons from the tip based on Fowler-Nordheim theory and the calculation of the electron trajectories for the prediction of the patterning line-width[1]. The simulations were executed for different tip materials, radii and opening angles as well as various tip-sample distances and applied bias voltages to gain insights in the complex dependencies determining the patterning process.
Based on these studies an analytic model was derived for the lithographic process. It consists of an approximation for the field enhancement at the complete tip surface and not only the maximal enhancement factor[2]. The field enhancement is used for the calculation of the electric field. The current density at the nanotip is obtained by Fowler-Nordheim equation and the estimated electric field strength at the tip. Additionally, an approximation for the relation between current density distribution at the tip and at the sample was derived taking into account the propagation of the electrons from the tip to the sample. With these three steps together the current density at the sample surface can be calculated.
Thus, the analytic model enables an estimation of the line width for a given tip and parameter set but also predicts the parameter set for the minimal feature size. Furthermore, it allows the optimization of the tip properties to get to the highest resolution capabilities of the FE-SPL technique.
The results of both, the analytic and numeric model, are compared with experimental data obtained by our AFM-in-SEM system[3].

[1] S. Lenk et al, "*2D Simulation of Fowler-Nordheim Electron Emission in Scanning Probe Lithography*", J. Nanomater. Mol. Nanotechnol. **5:6** (2016).
[2] S. Lenk, C. Lenk, I.W. Rangelow, "*Calculation of the enhancement factor for field-emission scanning probe Lithography*", submitted
[3] T. Angelov et al., "*Six-axis AFM in SEM with self-sensing and self-transduced cantilever for high speed analysis and nanolithography",* JVST B **34**, 06KB01 (2016)

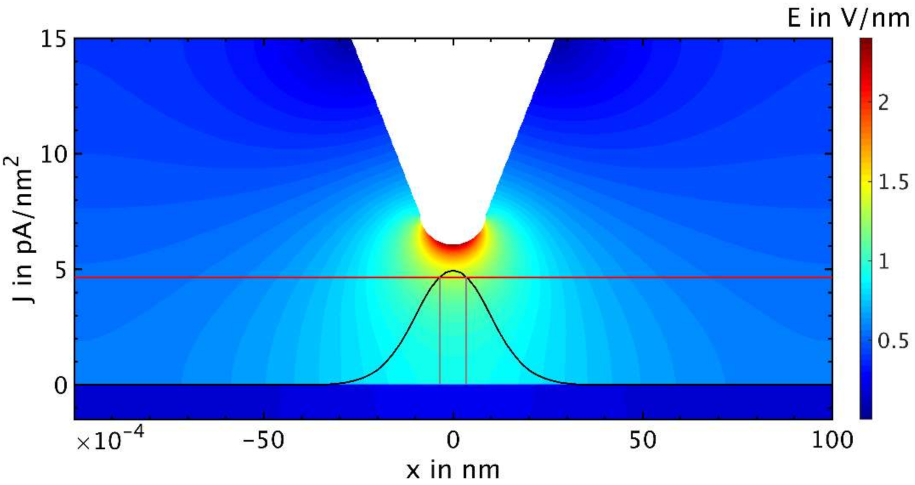

Figure 1: Electric field strength (color-code) and current density distribution (black line) for a certain parameter set: Results of the numeric model for the electric field strength between the nanotip and the resist covered sample surface and for the current density distribution at the resist surface are shown. The estimation of the line width (distance between gray lines) is based on the threshold value for lithographic reaction (red line).